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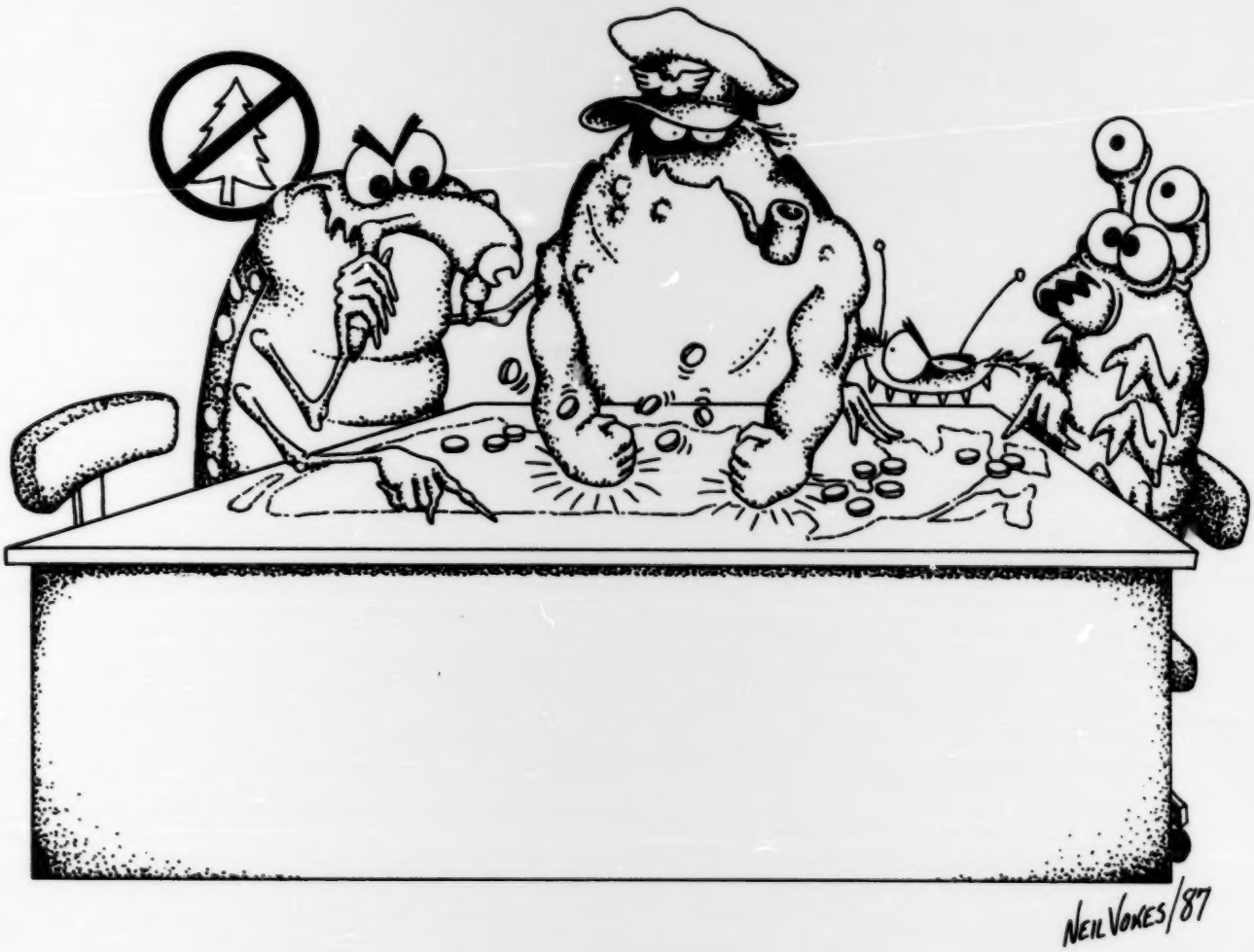
A national Geographic Information System for the Forest Insect and Disease Survey - requirements and selection

J.M. Power and D.H. Williams

Information Report PI-X-75
Petawawa National Forestry Institute



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A NATIONAL GEOGRAPHIC INFORMATION SYSTEM FOR THE FOREST INSECT AND DISEASE SURVEY - REQUIREMENTS AND SELECTION

Information Report PI-X-75

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Petawawa National Forestry Institute

1987

©Minister of Supply and Services Canada 1987
Catalogue No. Fo46-11/75-1987E
ISSN 0706-1854
ISBN 0-662-15686-2

Additional copies of this publication can be obtained from

Publications Distribution Centre
Petawawa National Forestry Institute
Chalk River, Ontario
K0J 1J0

Telephone: 613-589-2880

Cette publication existe aussi en français sous le titre **Un système national d'information géographique pour le Relevé des insectes et des maladies des arbres - analyse des besoins.**

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ABSTRACT

Geographic Information Systems can be used by the national Forest Insect and Disease Survey (FIDS) to automate infestation map production and to analyze the spatial qualities of insect and disease interaction with the forest. The identification of requirements for spatial data handling resulted in the selection of microcomputer-based Geographic Information Systems for distribution to FIDS regional units.

RÉSUMÉ

Le Relevé des insectes et des maladies des arbres (RIMA) peut utiliser des systèmes d'information géographique pour automatiser au niveau national la production des cartes d'infestation et analyser les paramètres spatiaux de l'interaction des insectes et des maladies avec les forêts. À la suite de la détermination des besoins pour le traitement des données spatiales, des systèmes d'information géographique utilisables avec des micro-ordinateurs ont été choisis pour les équipes régionales du RIMA.

ACKNOWLEDGMENTS

We wish to thank L. O'Brien of the FIDS Technology Development Project for his work in the investigation and selection of a system, and to the FIDS Heads at the Pacific Forestry Centre, Great Lakes Forestry Centre, and at CFS-Maritimes for their cooperation during site visits by the authors. We are also grateful to L. Magasi, D. Lachance, A. Van Sickle, and T. Moore for reviewing this manuscript.

A NATIONAL GEOGRAPHIC INFORMATION SYSTEM FOR THE FOREST INSECT AND DISEASE SURVEY - REQUIREMENTS AND SELECTION

INTRODUCTION

The Forest Insect and Disease Survey (FIDS) is a program of the Canadian Forestry Service (CFS) responsible for the collection, processing, and dissemination of information on forest insect and disease conditions of Canada. It provides a crucial component of data for the protection and management of Canada's forests and furnishes data for quarantine decisions. FIDS prepares annual estimates of pest occurrence by species, location, area of forest affected, and intensity of damage. These data are used to provide continuous monitoring of pest activity during and between outbreaks, to support research, and to design more detailed surveys of specific or operational interest. A major concern of FIDS is the timely provision of accurate natural pest occurrence information.

A large part of the data the Survey collects is now retained in an information system called FIDSINFOBASE. The system was developed for FIDS using the INGRES relational database management system, providing nationwide access from a dedicated VAX 11/750 computer (Power 1986). The system contains: data on the ground survey of insects and diseases and the associated specimen analyses collected by FIDS and its predecessors across the country over the past four decades; ground plot data from the Acid Rain National Early Warning System; and, insect and disease catalogues.

Another category of data, which could be handled by a computer system on a national basis, is that which deals with the geographic location of the forest and its associated pests. Specifically, these data consist of point locations of plots and outbreaks, areas of infestations, and areas or grids delineating forest stands or summaries of stand inventory data, including related descriptive or attribute data.

The FIDS operations currently use manual techniques for gathering, storing, manipulating, and retrieving data. An opportunity exists to improve the efficiency of this operation and to increase the quality, quantity, and availability of this information through automation of its components. New forms of data analysis may be achievable. Geographic Information Systems (GIS) technology has already made great strides with forest inventory operations. With the identification of GIS requirements in FIDS at a national scale, the agency can proceed to test and implement these systems on a standard basis across the nation, at a manageable pace.

This report looks at the potential application of GIS in the Survey, and the process we adopted to determine requirements and selection of a system. The report is directed at the resource management community interested in resource mapping applications and the selection process used by FIDS for microcomputer Geographic Information Systems. We have experienced numerous requests for this type of information.

DETERMINING REQUIREMENTS

The authors met with the three largest FIDS units in the country to document and analyze current operational procedures which may benefit from GIS technology. Other processes which are not now realized, but may be feasible upon the introduction of GIS technology, were noted. The needs for these tools were also identified through inquiry with both FIDS management and staff. Current and future FIDS information processing requirements were then related to GIS processing functions. General specifications for a system, and the manner in which they could be implemented, were formulated.

The current utilization of Geographic Information Systems in the CFS was a major consideration in developing a scheme by which FIDS can adopt this new technology. During the study, systems were identified that were cost effective, had lower operating overheads, and were potentially manageable by FIDS units either as an alternative or a complement to current CFS Geographic Information Systems. This would assure a more successful implementation at an acceptable cost. As a result, a number of microcomputer-based systems were investigated either on site, or through the literature, to determine the suitability of low-end systems for FIDS to get started with, without the high cost and complexity normally associated with minicomputer-based systems.

FIDS ACTIVITIES

FIDS spatial data processing requirements can be categorized by reviewing the Survey's present and future potential activities that are related to the processing of spatial data. These activities can be categorized as belonging to two sets:

a) FIDS annual survey and report

The CFS, through its regional FIDS units, conducts a continual overview survey to detect, monitor, and assess the occurrence and significance of forest pests. This survey differs in scope, intensity, and timing from region to region, but similar methods and procedures are employed across the country.

Aerial surveys are conducted during the summer months to sketch-map areas of infestation, usually at a scale of about 1:100,000. At the end of the field season, the FIDS Rangers return to the regional labs to process the sketch maps. This process involves:

- transfer of the areas of infestation from the sketch map to a permanent base map;
- reconciliation of current areas of infestation with those recorded during previous years;
- measurement and tabulation of the areas of infestation.

This detailed information is provided to various provincial and industrial agencies as quickly as possible. The infestation maps are transferred to a small scale map of standard form for publication in annual reports. In the future, FIDS may expect demands for faster and more accurate production of

maps of varying scales, but the basic reporting requirement will not change substantially.

b) New initiatives in research and reporting

Many applications exist within FIDS for data processing which have not been undertaken because GIS tools were not available. Many beneficial applications can only be envisioned by the FIDS staff after understanding the potential use of Geographic Information Systems in their work. The FIDS staff at the Pacific Forestry Centre are an exception in that they have recently gained experience on new applications through use of a GIS; this is explained in more detail under the "System Selection" section of this report. New initiatives in research and reporting would bring about further GIS applications, in particular the creation and manipulation of an historical database, and the integration of survey data with other data sets. The following is a list of proposed applications:

1. Improved survey design

   A spatial database which records the location and nature of infestations, and related climate and physiography, is useful for designing annual surveys, because there is an effort to monitor the status of infestations of previous years.

2. Improved hazard rating

   The history of an infestation, specifically the number of years of successive defoliation, can be used to form statements on probable mortality or growth loss. The probability of outbreaks in future forest rotations, together with the mortality and growth loss data, must be considered in determining the rate of forest harvest.

3. Improved quarantine decisions

   One use of the FIDSINFOBASE system is to improve the basis for forest quarantine decisions. The integration of more detailed data would provide better information for increased protection from pests within Canada and offshore, and continue to provide the necessary basis for issuing phytosanitary certificates enabling exports of forest products. An infestation map database could be merged with FIDSINFOBASE via the UTM coordinate recorded. This integrated database could be used to delineate and retrieve specimen records associated with an infestation, for purposes of quarantine, pest analysis, or collection management. The database would facilitate the analysis of pest survey data for improving hazard rating systems. FIDSINFOBASE could be used to provide incidence and intensity (severity) values for selected geographic areas. Isopleth lines would be created as a basis of hazard rating these areas.

4. Analysis of the relationships between biophysical factors and pest infestations.

   A similar application of FIDSINFOBASE and infestation map data could help identify or clarify relationships between the occurrence and severity of

infestations and biophysical factors such as temperature, precipitation, and terrain factors.

5. Integration of FIDS data with forest inventory data

Integrating the FIDS spatial database with stand-level inventory data would allow the identification of specific stands at risk from an infestation. Integration with inventory summaries such as the national inventory of the Canada Forest Resource Data System would delineate broad areas of infested forest. Statements on growth and volume losses, and mortality due to infestation, could be made. Prediction of infestations would be aided with the addition of climatological, physiographic, and ecological data.

6. Mapping and analysis of remote sensing data

As the resolution of operational remote sensing systems improves, and signatures of impact of potential pests are identified, greater use of remote sensing techniques for pest surveys are anticipated. A GIS would provide capabilities for the mapping and analysis of these data.

7. Analysis of biological control potentials and improved forecasting

The integration of the infestation database with a parasite database (e.g. 11 000 records already exists for the Pacific Region) could be a significant aid to the research and interpretation of native and introduced parasites, predators, and other control factors. This would greatly facilitate the manipulation and analysis of existing records.

GIS FUNCTIONS

Geographic Information Systems are characterized by a set of functions describing the data input, manipulation, and output. The application of these functions with the FIDS activities are described as follows, with the functions underlined.

A GIS would find application throughout the current survey and reporting process. The sketch maps would be digitized and displayed on the monitor, with the previous year's map displayed as a background. The areas of infestation could be reconciled between years and allow FIDS Rangers to identify verified expansions and contractions in the perimeter of the infestations while transferring the sketched information. Corrections to maps already entered would be accomplished using the map editing GIS functions. The number of discrete infestations and area of each infestation by severity classes would be calculated automatically with the map measurement functions. Production of special maps for various purposes would be possible using the map manipulation and the map drawing functions to create maps to order. Changes of scale required to produce the publication map would be accomplished automatically by standard map drawing functions.

The functionality of a GIS will expand when the activities identified under new initiatives in research and reporting are included. Maintaining an historical database is integral to GIS applications and requires only

that map files be organized and labelled. Analysis of two or more coverages (digital analogues of maps) within databases requires the overlay capability of the map manipulation function. Specifically, forest inventory data would be overlaid on the FIDS infestation maps, resulting in a new set of infested areas stratified by inventory types. Integration of additional datasets, such as ecological zones, and climatic and physiographic features, would result in further stratification of the infestation areas. The map measurement and map drawing functions would then be used to create maps and reports from the integrated database.

TECHNICAL REQUIREMENTS

Input/update

1. Digitization

   The workstation would include either a large 90 x 120 cm digitizing table and/or smaller, if maps can be accommodated, such as a 70 x 70 cm table. Control would be provided through a table- or screen-based menu. The digitized data and text describing attributes should be displayed on a graphics monitor against a background retrieved by the user from the graphics database. Map editing capabilities should be available at the digitizing stage.

2. Editing and verification

   Upon completion of the digitizing process the polygons must be checked for their topological correctness insofar as being incomplete or having extraneous graphics. Node snapping (closing gaps in incomplete polygons) and automatic removal of dangling strings (extraneous lines usually created by overshooting while trying to close a polygon during digitizing) must be featured in a GIS. During this process, manual editing must be possible. The system may automatically weed out unnecessary data points in order to describe the polygon at a certain level of accuracy. Once clean, the digitized maps are stored in a graphics database. This process should automatically assure that the map graphics are topologically in agreement with the graphics of adjacent maps already in the system. Edge matching of polygons which run from the input map onto an adjacent map must be done at a specified tolerance. The system must be capable of permitting manual editing and unmatched edges.

3. Throughput

   Nationally, up to 200 map sheets per year will be input. The bulk of the work would be done during late summer or fall months. Each map sheet may have up to 500 polygons, but the average will be under 50 per map.

4. Accuracy

   Polygons of infestation are very roughly sketched, hence high precision digitizing is not necessary.

5. Attributes (labels)

Attributes information associated with each infestation polygon is short and uncomplicated. It will normally consist of information on the agent causing the infestation, the host, and the severity of infestation. Map attributes will include the year and map reference.

6. Source document

The input document is usually a 1:100 000 scale NTS map or smaller scale map.

7. Personnel

Digitizing would be done by the FIDS Rangers, technicians, and students. This component of the system should be friendly to the inexperienced user and should not assume computer literacy.

8. Backlog

All or most of the FIDS maps which show pest infestations may be considered as a backlog, and should be entered into an historical spatial database. An example of the load can be taken from the backlog at the Pacific Region, where about 150 maps per year exist for 1975-1985, and about 50 maps per year prior to 1975.

9. Import/export

It is required that the GIS has the capability to import data from other databases, as a minimum from current CFS GIS installations. Remote sensing databases can be another source of data. A similar capability to export FIDS infestation polygons to CFS Geographic Information Systems or provincial data systems would be desirable.

Database management

1. Graphics

The graphics database should be sufficiently topologically sound, such that the map manipulation, edit, drawing, and import/export functions can be executed efficiently. The graphics data must be maintained in a fashion where all input maps are unified into one or a set of coverages. The topology of lines and polygons in the database are independent of the fact that they were input into the database as "maps". Effectively, maps will be combined so that any geographic area covered in the database can be analyzed or extracted for output.

2. Attributes

Data should be manageable according to the rules set out in the design of relational databases. This is particularly important for integration with the other FIDS relational databases, such as those in FIDSINFOBASE, for data retrieval. It should be expected that the requirements for storage

of associated attributes will grow as users become aware of the capabilities of GIS.

Map manipulation (spatial processing)

1. Area selection

The ability to select map windows interactively is required. Selection of map polygons according to their associated attribute information is also a need. An example of this function would be a display of all infestation polygons by pest species where mortality exceeds 40%.

2. Corridor analysis

The ability to generate corridors about linear features and to use those corridors for area selection is necessary. An example would be to display the portions of all infestation polygons which are within 90 metres of a road.

3. Circles, grids

The ability to generate a circle or grid of a given dimension, and perform an overlay on the spatial data, is required.

4. Measurement

The calculation of areas of polygons with the automatic detection and subtraction of enclosed polygons is needed. As well, there is a requirement to calculate the linear distance between specified points.

5. Graphics editing

The ability to interactively edit the graphics database, including dissolving common boundaries between polygons with the same attribute, reclassifying polygons, replacing, or creating polygon boundaries and merging polygons, is necessary. Also, the ability to remove polygons that fall below a specified tolerance, as well as reclassifying and merging others, before outputting at a small scale, is very useful. This will avoid cluttering when the output is for maps on large areas, such as provincial or national maps.

6. Overlay

The ability is required to overlay polygons from maps of different themes. Substantial overlaying can be done to analyze successive years of defoliation, to extract forest inventory data, and to relate infestations to other coverages such as weather and physiography.

Map output

1. Quality

   Map quality requirements are low, when considered in terms of the high quality map drafting systems currently on the market. Precision considerations are generally irrelevant in light of the accuracy of the input data; however, some special studies may have more refined needs.

2. Drafting standards

   Symbols, line weights, fonts, or other special cartographic features have not yet been identified as a requirement.

3. Colours

   A minimum of four colours for plotting should be available, with various patterns for differentiating polygons.

4. Labels

   Labelling expectations are not high; however, the ability to interactively place a label in a polygon, and change its position, size, and rotation is required. Map labelling with titles, legends, and scales must also be flexible.

5. Scale

   The drawing system must be capable of producing a map to a specified scale, independent of the scale of the input document.

6. Size

   The drawing system must be capable of producing a map of equivalent size to the input document (i.e. National Topographic Series of maps), and a publication sized map, as specified by the user.

7. Throughput

   Each input sketch map will be displayed or plotted for error control and interpretation. The plotting of different themes on a standard background map will permit creation of multiple products. The map throughput requirements for "new initiative" activities are not yet known.

SYSTEM INVESTIGATION

To meet the needs of FIDS in its current surveying and reporting activities, large scale Geographic Information Systems such as those in common use in forest inventory systems are not necessary. The potential activities catagorized under "new initiatives", however, would require a GIS with full scale spatial data handling capabilities, such as overlaying.

A logical approach towards implementing GIS technology into FIDS would be to introduce low cost, simple systems which can be grasped easily with a minimum amount of training. Operation with these types of systems would assist in clarifying the new initiatives which could be run on larger systems. These systems would be able to be operated on a stand-alone basis to accept map data through digitizing, to retain them in a small database, to undertake basic measurements such as area calculation and line length, and to display or plot these graphic data at different scales, line weights, colours, and patterns. Some of the smaller systems which normally reside on micro-computers were investigated either through literature or through on-site visits by the authors.

With the recent advances in microcomputer technology, it was found that many of the full-scale capabilities found in mini or mainframe-based systems are now available on the micros. Cost differences make these systems very attractive for acquisition and distribution within an organization such as FIDS. This option only became available in 1985, and many advances have occurred since then as demonstrated by the release of a number of powerful systems by software developers.

An important factor in the selection of microcomputer-based Geographic Information Systems is their ability to be integratable with full-scale Geographic Information Systems for communication, storage, and processing of spatial data. In this environment, the GIS work will be distributed to the micro systems, with a central mini-based GIS for storage and for heavier processing, such as overlaying. The CFS currently operates a large-scale GIS system, ESRI ARC/INFO, on a Digital Equipment Corp. (DEC) VAX computer. This system could likely serve in a central processing role in a national system for FIDS.

The CFS also has a new single-user GIS at the Pacific Forestry Centre (PFC) FIDS unit, acquired primarily for research applications. It is used operationally in loading infestation maps, overlaying, and producing plotted maps for presentations and inclusion in reports. This system, known as OVERLAY, was developed by Northwest Digital Research Ltd. for Hewlett-Packard minicomputers, in cooperation and consultation with the PFC FIDS unit. The system uses an advanced form of raster, or grid cell representation of infestation areas, using "quad-tree" data structures. This feature enables rectangular groups of cells to be represented by a single larger cell, which provides for more efficient data storage. At minimum, the PFC OVERLAY system would be regarded as an important source of new techniques in GIS analysis for FIDS use in regional systems.

SYSTEM SELECTION

The selection of a microcomputer-based GIS depended on the use of current GIS systems and expertise already in existence in the CFS, namely the VAX ARC/INFO system at PNFI, and the PFC OVERLAY system. The VAX installation would be well suited for central processing and storage purposes. The direction taken would be towards a distributed system where functions will operate either on the central minicomputer GIS, or the regional micro Geographic Information Systems, wherever optimal.

Plans proceeded for the acquisition of GIS software packages for use at PNFI for applications development and for pilot testing at CFS-Maritimes and the Northern Forestry Centre. Other regions will have installations depending on the outcome of this first phase of implementation. The PC/AT microcomputer, regarded as the industry-standard for micro systems, was selected. It is important to select a computer which is low in cost, easy to maintain, has a large software base in particular with Geographic Information Systems, has the highest probability for an increasing software base in the future, the highest probability of sustained support and upgradability in the computer community, and commonality with systems of other resource management agencies.

Specifications required for FIDS were developed for the micro GIS software (see Appendix 1). These specifications are based on the requirement to operate with the PC/AT and take into consideration the substantial investment and availability of the VAX ARC/INFO system at PNFI. The specifications were sent out to 14 software vendors in the form of a request for proposal in September, 1986. Five vendors returned proposals which were evaluated against the specifications, to determine the best system. The PC ARC/INFO system from ESRI Canada Ltd. was selected, with acquisition in March, 1987.

Justification for this system was based on the following factors:

- vectors are used to describe linear surfaces, which was regarded as the best method, avoiding logic problems in overlaying, and retaining the integrity of these surfaces;

- the system would conform the best to a distributed environment, allowing smooth data transfer from host to micro in an immediately useful state, with little operator intervention.

- the system is most compatible to the host system, as both are basically identical, reducing training, complexity, overhead, and support requirements.

- the system can be acquired in modules, so one needs only to purchase those that are required;

- the system permits expansion to larger computers as the need arises;

- the vendor is well established, posing a low risk to clients losing future support.

CONCLUSION

Geographic data is important to the Forest Insect and Disease Survey. Providing capabilities to gather and analyze these data through Geographic Information Systems will enable the Survey to provide more and better information on forest pest conditions for managers. Integration of a GIS into the current FIDSINFOBASE information system will allow geographic data to be related to much of the other biological data that the Survey collects and analyzes.

The use of microcomputer-based Geographic Information Systems will provide a cost-effective and locally-resident tool for the regional FIDS units. Data can be shared, and larger-scale storage and processing can be accomplished through the connection of the regional microsystems to a large central GIS.

LITERATURE CITED

Power, J.M. 1986. FIDSINFOBASE - The Forest Insect and Disease Information System. Can. For. Serv., Petawawa Natl. For. Inst., Inf. Rep. PI-X-65.

Appendix 1. System Specifications
(as issued in Request for Proposal)

A. MANDATORY REQUIREMENTS

A.1 Operating Environment

A.1.1 The required GIS software must run on the IBM Personal Computer AT under the IBM DOS 3.1 operating system (and subsequent versions).

A.2 Compatibility

A.2.1 The proposed system must be able to exchange data, without user modification, with the DEC VAX 11/780 version of ESRI's ARC/INFO. This includes all attribute data and files associated with the map which are managed through INFO portion of the system.

A.2.2 It is FIDS Technology Development Project's intent to test for compatibility by running a compatibility test.

A.3 Functionality

A.3.1 The software must be able to allow digitizing via a cursor, of points and polygon data, or via a digitizing table, retaining the topology of the polygon.

A.3.2 Digitizing must be accompanied by a real time monitor display of digitized data.

A.3.3 The software must be able to permit the input of attribute data both during and separately from the digitizing process.

A.3.4 The GIS must be able to plot our geographic data.

A.3.5 The software must be user-friendly and ready to operate without further systems development.

A.3.6 The total software package must be cost-effective.

A.4 Documentation

One (1) copy of all relevant manuals and documentation must be provided with the software for each copy of the software purchased.

B. DESIRABLE REQUIREMENTS

B.1 It is desirable that the command line syntax be similar to ESRI's ARC/INFO.

B.2 The GIS should be able to drive Calcomp digitizers and plotters, and possibly Hewlett-Packard plotters.

B.3 This software should not require additional hardware over the basic configuration of a microcomputer with 640K, 20MB fixed disk drive, a monitor, a digitizer, a plotter, except for the minor parts such a mouse.

B.4 The GIS should support either an IBM compatible colour graphics monitor or an enhanced colour graphics monitor.

B.5 The software should be able to automatically measure the areas and line lengths of polygons or linear features.

B.6 The GIS should permit editing and cleaning of topological data such as finding incomplete polygons, dangling strings, and slivers, and permitting closure of polygons and removal of strings and slivers automatically through specification of a tolerance limit and through an optional manual clean-up procedure.

B.7 The software should easily piece together maps input into the system so that they are topologically and geographically sound.

B.8 The GIS should be able to treat a set of maps resident in the system that logically connect as a single map for analysis or plotting.

B.9 The software should be able to capture layers to geographic data and retain their topological and geographic relation to each other.

B.10 The GIS should manage the geographic data effectively using a data manager.

B.11 The software should be able to function with the VAX ARC/INFO system in a truly distributed sense such as being able to retrieve data from the VAX system, initiate and control processes in the VAX system, and upload data to the system directly into an ARC/INFO database.

B.12 The GIS should function on a remote workstation with the VAX ARC/INFO system.

B.13 The software should closely follow the command syntax and modular structure of the ARC/INFO system for data capture, clean-up, database operations, and data output.

B.14 The GIS should be able to overlay geographic data during plotting.

B.15 The software should be able to conduct topological overlaying on at least a grid cell basis.

B.16 The GIS should convert polygons to grid and reverse, and retain these conversions in the database.

B.17 The software should provide various features for plotting of geographic data such as user selectable line size, colour, and style, polygon shading, symbol identification of point data, support of at least four colours for these features, selection of text fonts, automatic and manual positioning of text, ability to design, and place titles and legends, plotting at selected scales. These features may be generated according to data attributes. (Plotted data should be accompanied by a real time display of plotted data on the monitor.)

B.18 The GIS should be able to reclassify, merge, and dissolve polygons based on user provided criteria.

B.19 The software should weed out points and polygons based on user provided tolerance levels for the purpose of eliminating cluttering during scale change for output.

B.20 The GIS should work with and convert from various map projections, such as Universal Transverse Mercator and Lambert.

B.21 The software should be able to generate grids, lines, and points from coordinate data.

B.22 The GIS should produce basic reports on area and line length statistics and listings of attribute data for map layers as requested by users.

B.23 A windowing capability would be useful.

B.24 The software should be able to control processes via a monitor and/or a digitizer (tablet) mounted menu.

B.25 Documented source code should be provided with the software.

B.26 The GIS package should be user friendly such that it does not require the assistance of a systems analyst in day to day operations.

B.27 A program of regular update of software with corrections and improvements must be available by the vendor.

B.28 Two levels of documentation should be included: one directed at the users of the software, and the other directed toward systems analysts.

B.29 The opportunity should exist for vendor provided training for system management and users of the software.

B.30 The vendor must demonstrate a satisfactory current and potential user base for their micro GIS software.

B.31 The vendor must demonstrate a satisfactory financial stability to that user support and system upgrades in the future are highly probable.

B.32 The GIS must be available for acquisition immediately, not pending any further development in meeting its stated ability to fulfil our specifications for a system.